V.—*Experimental Researches on the Depressions of the Wet-bulb Hygrometer.* *By* JAMES PRINSEP, *F. R. S. Sec. As. Soc.*

At the first meeting of the British Association for the advancement of Science, the Committee appointed to draw up a list of desiderata in the various departments of science, included among the objects of meteorological inquiry an investigation of the theory of the wet-bulb hygrometer: and in the circular then prepared, and at the subsequent annual meetings repeated, the Meteorological Committee was pleased to compliment with its favourable notice the papers published anonymously on this subject in the Calcutta "*Gleanings in Science.*"

The requisition of the British Association appears to have remained unanswered until the Dublin meeting in August last, when Professor APJOHN, of the Royal College of Surgeons in Dublin, brought forward the results of his own experiments, and expounded a simple and elegant formula which he had in every case found to agree with them, and to be practically applicable to the various conditions of the problem.

Dr. APJOHN's papers are published in the Philosophical Magazine for March, October and December, 1835; and it is principally an observation in the opening of his memoir which induces me to revert to the subject. "In the first report," he says, "mention is made of a register of observations kept in the East Indies, which, as belonging to high temperatures, would necessarily exhibit great depressions, and would therefore be valuable as a standard of comparison; but I have in vain searched for the Calcutta Journal '*Gleanings in Science,*' in which they are said to be contained."

In one respect we may deem it fortunate that the sluggish circulation of our humble periodical had not attained the shores of Ireland; if to the want of the data which "the Gleanings" might have furnished we are indebted for the series of experiments undertaken by Dr. APJOHN; for the more varied these may be, and the more numerous the observers, the more confidence may reasonably be placed in any formula that may accommodate itself to the whole.

I might without vanity claim to my own share as large a portion of the labour of experimental investigation as has rewarded the patience of any observer of the wet-bulb indications; having, with little intermission, registered daily observations since 1822; but I am more anxious to claim for my lamented fellow labourer, Captain HERBERT, the merit of having treated the theoretical portion of the subject—I will not say in a more philosophical manner than had hitherto been followed, because GAY LUSSAC had before exercised his masterly hand upon it, but,—in a manner equally sound in principle and creditable to himself, considering that he had not the means of referring to the original memoir of the French philosopher, and that he had only the erroneous views of the *Edinburgh Encyclopedia* to guide, or rather to misguide, him.

In Captain HERBERT's first paper*, he reviewed with unsparing criticism the paralogistic reasonings of the Encyclopedist, Mr. ANDERSON, and pointed out the true basis of the wet-bulb depression so nearly in accordance with the views of Dr. APJOHN, of Dr. HUDSON his coadjutor, and of M. GAY LUSSAC, that it establishes the general correctness of all, although the particular formula which he proceeded to build upon it, naturally agreed best with the data that my own experiments, published also in the Gleanings of March 1829, had furnished to him. He had fortified himself for the investigation by previous study of the doctrine of the latent heat of gaseous bodies, upon which subject he had published a brief but luminous essay in the Oriental Magazine for September 1827; and certainly no subject has so much needed a sprinkling of rationality to lay the dust of unphilosophical hypothesis which even yet remains to obscure a plain question; so much so, that Dr. HUDSON, one of our Dublin competitors, while he acknowledges the dependence of the problem on the relative capacity for heat of air and aqueous vapour, "will not dwell on this method nor the corrections it would require, placing no reliance on the truth of the requisite assumptions†."

But before entering into a review of the various theories that have been adopted by others, it may be preferable to describe in as succinct a manner as is consistent with clearness, the course I originally pursued to supply the experimental requisites for calculation, and upon which I ventured to form a table‡ for the reduction of wet-bulb indications to hygrometric degrees in 1828-9§. I have recently concluded a second and even more extended series of similar experiments, with the advantage of superior means and apparatus, which have enabled me to prosecute some branches of the inquiry that I believe have not before engaged sufficient attention.

In all hygrometric speculations it is usual to consider the state of extreme moisture, or the point of aqueous saturation of the air, as

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* Gleanings, Vol. I. p. 45.

† Phil. Mag. Vol. VII. p. 259.

‡ Gleanings, Vol. I. p. 81.

§ Before this period in 1827, I furnished a "table of multipliers" for reducing the depressions into aqueous tensions, calculated from three years meteorological observations at Benares with this instrument and the hair hygrometer. The Royal Society, who did me the unexpected honor to publish my registers, retrenched this table, and the notes which accompanied it. They had been, however, in the mean time printed in the Calcutta *Oriental Magazine* for March, 1827.

represented by 100° ; while extreme dryness, or entire absence of aqueous vapour, is expressed by 0°. The intervening degrees comprehend every intermediate state of moisture that can possibly occur, and conveniently express the percentage of actual moisture present, or as it is more scientifically termed, the *centesimal* tension of the vapour.

The point of saturation on the wet-bulb instrument (100) is indicated by 0°, because evaporation, and the cold consequent on it, then ceases. The questions to be solved then are, 1st, What is the maximum depression, which corresponds to perfect dryness (0) in the assumed scale, for every temperature ?—and 2nd, What is the value of each intermediate degree (Fahrenheit) of depression of the wetted thermometer in terms of the *centesimal tension* or 100 hygrometric degrees above alluded to ?

I. There is one very easy method of attaining the first object : viz., by exposing a wet-bulb thermometer to a current of perfectly dry air of various temperatures. This was the mode pursued by Gay Lussac between the temperatures 32° and 70°, in 1827 : by myself in 1829, between 70° and 140°, and recently continued up to 700° Fahrenheit : it is the plan proposed to be pursued by Dr. Hudson*, and employed in the test experiments of Professor Apjohn in 1835†. In fact, this is the only accurate plan of testing the maximum depression, which is to represent 0° on the hygrometric scale : for the exposure of a wet-bulb thermometer in *still air* dried to the utmost, fails to produce a maximum, the instrument being necessarily surrounded with a medium not perfectly dry. Dr. Apjohn makes the error by this method $\frac{1}{6}$th ; I have found it about $\frac{1}{10}$th.

II. The second question, as to the value of intermediate depressions ? may be ascertained by drying the air to various points, as 20, 30, 40 per cent. which can be done by exposing it to various saline liquids, or more conveniently to sulphuric acid of different strength, and then submitting the thermometer to a current of it as before. This mode was used long since by M. Gay Lussac in testing the value of the degrees of Saussure's hair hygrometer, and it was followed by myself in a repetition of the same train of experiments in 1825‡. To obtain, however, an equable current of wholly or of partially dried air for a sufficient duration of time, is by no means easy ; nor do I think that air merely passed through a tube containing sulphuric acid or chloride of lime, without remaining in protracted contact with it, would be thoroughly deprived of moisture. At any rate, to ensure confidence, there should be the means at hand of record-

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[*] Phil. Mag. Vol. VII. p. 260.

[†] Ditto, p. 271.

[‡] See Brande's Journal of the Royal Institution, XXII. 28.

ing its actual state. M. Gay Lussac merely dried his air by chloride of lime, and his depressions will be seen to be all below the mark.

Professor Apjohn states, that he pressed air from a caoutchouc bag through three of Wolfe's bottles, passing it thrice through the acid on its way to the thermometers. This must have been inconvenient and difficult to regulate, and the knowledge of the real condition of the air was withheld; although there can be little doubt that it was thoroughly dried. My own method was to dry the air previously for days or even weeks in a large gasometer, whence it could be driven in a very uniform current. The secret of the facility I enjoyed in this respect lay in the substitution of *cocoanut oil* for *water* in the reservoirs of my gasometers, which not only prevented the accession of moisture, but preserved the gas unaltered for any length of time;—I have fearlessly lighted a jet of hydrogen that had stood *two years* in my gasometer!

There are other modes of obtaining intermediate stages of dryness: the most obvious is by using the atmosphere itself of a dry or damp day, first ascertaining by Dalton's dewpoint experiment its actual hygrometric state, and noting the corresponding indication of the wet bulb thermometer; the averages of a good meteorological register are of this kind. Again, when damp air is artificially heated by passage through a warm tube, the capacity of the warm air for water being increased while the dew point remains unchanged, an effect tantamount to using drier air may be obtained and exactly estimated. The rarefaction of air also, (in the absence of the means of fresh supply of water) produces a measurable diminution of the ratio of humidity per given volume. These simple methods have been used by all experimenters, particularly by Leslie himself, the original projector of the evaporation-hygrometer.

In describing, therefore, my experiments directed to the two main inquiries, it will save some circumlocution to designate the methods pursued as, 1st, dry air current; 2nd, current of air having given aqueous tension; 3rd, heated air of known tension; 4th, rarified air do; and 5th, dew-point comparisons.

But there are other important branches of inquiry necessary besides the above two, ere we can hope for a formula to satisfy all conditions of the wet-bulb problem.

III. The experimental effect of diminished and augmented atmospheric pressure?

IV. The amount of depression in other gaseous media? and

V. The effect of greater or less velocity of the air on the temperature of evaporation? This effect has been sufficiently examined by

DALTON himself, as regards the *quantity* of water evaporated. Theoretically, however, it has no influence on its temperature; and this is confirmed by experiment, under certain limitations.

With such an appalling complication of influences to be traced out, it is hardly to be wondered at that M. GAY LUSSAC himself should have given up the prosecution of the wet-bulb problem, or that the Editor of the Royal Institution Journal* should have joined in its condemnation at a time when the elegant method of DANIELL was winning general favor. Nevertheless, independently of its direct preferability as the most simple mode of registering the humidity of the air, the problem itself is of the highest importance, in the solution not only of very many phenomena in pneumatics and meteorology, but of such standard doctrinal points of theory, as the latent heat of gases and steam; and others of practical utility—as the artificial production of ice and cold. I shall have occasion to adduce a few illustrations ere I conclude; but I must now proceed to my first series of experiments.

§ 1. *On the curve of maximum depression.*

The apparatus used for drying the air is sectionally depicted in Plate XXI. fig. 1, where *a* is a dish containing concentrated sulphuric acid enclosed in a 120 pint gasometer. Another similar dish rests in the glass double bell receiver *b*, wherein are suspended a hair hygrometer (the only instrument applicable as a tell-tale, and indeed an invaluable hygrometer for every purpose) and a delicate thermometer. Through this receiver the air of the gasometer passes to the stopcock and short glass tube *c*, in which is placed a small thermometer, covered with muslin and dipped in distilled water at the moment before the experiment commences.

The only difference in the order of M. GAY LUSSAC's experiments, being, as I have stated above, that he employed chloride of lime *without a tell-tale hygrometer,* while in my first Benares series I employed the same salt *with this addition,* it would be easy to apply to that philosopher's results the correction I found necessary for the want of complete desiccation in my case. At all events, as his series comprehends low temperatures, which were beyond my reach in India, it will render my review of the question more complete to insert his valuable table, converting the centigrade expressions into those of Farenheit's thermometer. In the fourth column I have added the aqueous tensions† at the wet-bulb temperature; and in the fifth, the quotients of

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[*] Jour. Roy. Inst. XV. 296.

[†] By BIOT's formula founded on DALTON's experiments, and published in the Edinburgh Encyclopedia, Mr. ANDERSON's article *Hygrometry*.

the depressions divided by these tensions, which will be found to be the key to the formation of a *formula* for the problem.

Tab. I.—*Depressions observed by M. Gay Lussac.*

Temp. of dry air t °	Wet-bulb therm. t' °	Depression wet-bulb D °	Aq. tens. at t'. f' in	Qut. of D ÷ f'	Temp. of dry air. t °	Wet bulb therm. t' °	Depression wet bulb. D °	Aq. tens. at t'. f' in	Qut. of D ÷ f
32.0	22.0	10.0	.139	72	57.2	38.7	18.5	.252	73
33.8	22.8	11.0	.143	76	59.0	39.5	19.5	.260	75
35.6	24.1	11.5	.153	75	60.8	40.6	20.2	.268	75
37.4	25.4	12.0	.157	76	62.6	41.7	20.9	.280	75
39.2	26.9	13.3	.166	74	64.4	42.9	21.5	.292	73
41.0	27.9	13.1	.172	76	66.2	44.0	22.2	.304	74
42.8	29.1	13.7	.179	76	68.0	45.1	22.9	.316	72
44.6	30.2	14.4	.186	72	69.8	45.2	23.6	.317	74
46.4	31.5	14.9	.195	77	71.6	47.3	24.3	.340	71
48.2	32.7	15.5	.204	76	73.4	48.4	25.0	.354	70
50.0	33.9	16.1	.213	75	75.2	49.5	25.7	.363	71
51.8	34.9	16.9	.220	77	77.0	50.5	26.5	.380	70
53.6	36.1	17.5	.231	76					

Average ratio of depression to aq. t., 74

It will be remarked, that with exception of the three or four last experiments, the depression follows a nearly uniform ratio to the aqueous tension, being 74 times greater. The air in the last four was doubtless not quite so dry as in the others; for in my own first series, which begins nearly where the French table leaves off, the depressions are found considerably in excess of M. Gay Lussac's results.

In the series in question the presence of the hair hygrometer enables me to make an approximate correction for imperfect dryness founded on a coincidence, which will be explained hereafter, between the curve of depressions and the curve of the hygrometer, so that nine degrees of the latter + or —, for instance, will nearly represent 9 per cent. + or—in the depression, near the dry extremity of the scale*. The barometric correction will be also explained further on.

Tab. II.—*Maximum Depressions determined at Benares.*

Temp. of dry air t °	Wet-bulb Therm. t' °	Observed depression. d °	Barom. at 32° B	Hair Hygrom. H	Corrected depression. D °	Corrected wet bulb t' °	Aqueous tens. at t' f' in	Quotient of D ÷ f'
72.5	47.2	25.3	29.43	9.5	27.5	45.0	.315	87
75.0	48.2	26.8	.52	9.5	29.3	45.7	.321	91
78.5	52.1	26.4	.30	9.5	29.3	49.7	.369	78
82.6	54.8	27.8	.26	9.5	30.3	52.3	.403	75
83.5	54.5	29.0	.25	8.	31.3	52.2	.402	77
84.7	55.0	29.7	.30	9.5	32.3	52.4	.405	80
85.0	55.0	30.0	.30	8	32.2	52.8	.411	80
85.0	54.8	30.2	.20	8	32.5	52.5	.407	80
90.2	56.8	33.4	.15	9	36.1	54.1	.429	82
90.3	56.7	33.6	.15	8	35.9	54.4	.434	83

In continuation of the foregoing, I will now give the Calcutta series, in which sulphuric acid was used in lieu of chloride of lime,

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* This mode of correction was not adopted in my former paper, and the depressions were consequently too low.

and a greater dryness consequently attained ; though in some cases I had not the patience to wait until the hygrometer marked 0 : in fact, if it did, there was usually enough of moisture in the passages of the gasometer to cause a fall of 1 or 1½ degrees in the tell-tale hair hygrometer, ere the air reached the vent.

TAB. II. *2nd pt.—Maximum Depressions determined at Calcutta.*

Temp. of dry air t	Wet-bulb Therm. t'	Observed depression d	Barom. at 32° B	Hair Hygrom. H	Corrected depression. D	Corrected wet-bulb t'	Aqueous tens. at t' f'	Quotient of D $\div f'$
°	°	°			°	°	in	
94.8	57.8	37.0	29.67	5	38.7	56.1	.459	84
94.6	57.3	37.3	.51	1 ?	37.7	56.9	.471	80
96.4	58.4	38.0	.43	2	40.0	56.4	.462	82
92.0	56.1	35.9	.50	3	37.0	55.0	.442	84
88.7	54.4	34.3	.55	3	35.2	52.5	.406	86
87.0	54.8	32.2	.44	4 ?	33.4	53.6	.420	79
83.1	52.1	32.0	.50	2	32.5	50.6	.381	85
88.2	54.5	33.7	.46	3	34.6	53.6	.420	82
82.6	51.7	30.9	.50	2	31.4	50.2	.376	84
80.9	51.1	29.8	.55	1	30.1	50.8	.384	78

The same uniformity in the quotients of the last column will be remarked in these two tables, but the average is now 81.8, considerably higher than the Paris result.

Having thus by the ordinary atmospheric temperature of a Calcutta laboratory in May, brought up my train of observations to 96° ; and finding that the depressions so much exceeded those for the same portion of the series ascertained at Benares by suspending a wet-bulb thermometer in a vessel of sulphuric acid heated successively from 90° to 140°*, I devised the following method of extending the dry-air current series to temperatures still more elevated.

In the first place, the gas-pipe of the gasometer was encased for about four feet of its length in a larger leaden pipe connected with my small steam engine, so that a current of steam could be maintained in the latter during the continuance of the experiments, as is shewn in fig. 2. Pl. XXI. The extremity of the gas-pipe terminated in a glass tube holding, first, a dry thermometer, and an inch further on, the wet-bulb thermometer, inserted through corks.

On letting on the steam, (the two thermometers being stationary at 92°,) one began to rise rapidly, while the other fell very slowly. I could not, however, succeed in getting the former to rise beyond 190°, though the steam itself was at 215°. The wet-bulb then stood at 85°.0 and it fell to 80°.4 at 180° :—80 at 170, and 79.5 at 166. The

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* See Gleanings, I. 79. I purposely exclude these results in the present place, lest they should confuse the view ; but they are, nevertheless, valuable in another sense, as shewing the difference, between the depression in calm air and in a current.

fluctuations of the dry thermometer being so considerable for a nearly stationary temperature of evaporation, it was somewhat difficult to determine the exact terms of coincidence; but the above are selected as the best from a great many readings recorded in my note book.

In a second experiment with air containing $\frac{6\cdot0}{100}$ ths of aq. ten. at 94°.3 (= $\frac{7}{100}$ ths at 170°) the dry thermometer became stationary at 170°, with the wet at 87°.7.

In a third trial, aq. ten .65 at 94.6 (= $\frac{6\cdot5}{100}$ at 180) the stationary points were 180, and 90.

In a fourth, dew-pt. 74.3 (aq. ten. = 4.4 at 190) the same points were 190 and 92.2—Bar. 29.50.

Barometer	Thermom. in curt. of air. °	Wet-bulb Thermom. °	Observed depression. °	Cen. aq. tens.	Corr. for do.	Aqueous tens. at t'	Quotient $D \div f'$
29.55	190	85	105.0	0 ?	0 ?	1.17	89
	180	80.4 ?	99.6	0	0	1.01	98 ?
	170	80.	90.	0	0	1.00	90
29.50	190	92.2	97.8	.044	+ 7.2 ?	1.17	89
	180	90.	90.	.065	+ 7.4 ?	1.12	87
	170	87.7	82.3	.07	+ 7.7 ?	1.00	70

Observing the very rapid increase of the evaporating depression with the rise of the temperature, I perceived that I might safely carry my experiment to much higher limits than the boiling point of water. I accordingly next passed the current of dry air through a porcelain tube maintained at a bright orange heat in a Black's furnace (fig. 3, Pl. XXI.) At the further end of the tube a lateral hole was perforated to admit the bulb of the thermometer, coated with two-fold muslin that it might hold a larger supply of moisture. It was necessary to watch the experiment carefully, as, the moment the water was removed, a sudden rise took place, which would have otherwise broken the thermometer, while the cloth and cork were instantly charred with the heat. The actual temperature of the dry current was then estimated in the following manner: a thermometer, with the tip of its stem left open, was held mid-tube in the position previously occupied by the wet-bulb. In a few minutes the mercury boiled off, shewing that the temperature somewhat exceeded 656°. A very thin slip of tin was instantly fused: one of lead was then held within the tube, but it required to be passed a little in advance of the position of the wet-bulb ere it melted:—we may therefore assume the heat of the dry air to have been under 700°. Two experiments agreed precisely in giving the temperature of evaporation 145°. With a very rapid current the wet-bulb thermometer fell to 144°, but probably the air had not then time to get thoroughly heated in traversing the furnace.

There would have been little satisfaction in carrying this train of research further, because of the difficulty of measuring the temperature; otherwise it is evident that the coated thermometer might be safely trusted in a much greater heat, ere it would itself reach even the boiling point of water under the ordinary pressure; an illustration of which will be hereafter mentioned, but, not being strictly experimental, it cannot be introduced here.

Having however accumulated abundant data for the formation of an experimental curve, I may proceed to throw them together in the form of a diagram (fig. 4.), and to compare at once the results with the various formulæ that have been proposed by different philosophers.

As, however, each author has employed different algebraic characters for working out the problem, it will be better first to bring them to common terms, adopting the most simple expressions: thus let

t = the temperature of the air.
t' = the temperature of a wet-bulb, or of an evaporating surface.
t'' = the temperature of saturation, or the dew-point.

then f, f', and f'' may be conveniently used to represent the *force of aqueous vapour*, at t, t', and t'' respectively. d, the depression, is of course $= t - t'$, and not absolutely wanted, but it is frequently a more convenient expression; and D may be also used to distinguish the *maximum depression* in dry air, when $f'' = 0$.

Now supposing the increasing temperatures, t, to be represented by the abscissæ of the divided line TT, the observed depressions may be laid off as ordinates, through the apices of which a dotted line being drawn, will form an *experimental curve of maximum depression*, for which a mathematical expression is required.

Next, to collect the materials for the theoretical curves to be entered in the same diagram, we must take a cursory view of the existing theories.

Leslie, who must be regarded as the inventor of the wet-bulb hygrometer, deserves the precedence in this inquiry. His experiments were conducted by approaching a dry and a wet thermometer together gradually towards a heated furnace in a closed chamber. The Professor calculated the hygrometric conditions of the air as its heat rose; and on comparing his results, he was led to the conclusion, that as the caloric necessary to convert water into steam was = 6000 degrees of his instrument, and the capacity of air was $\frac{3}{8}$ths that of water, the same measure of heat would raise an equal mass of air, 16000 degrees; and consequently that at the temperature of the wet-bulb, t', air would take up the 16000th part of its weight for each degree marked by his hygrometer, which is equal to the 2880th part for each degree of depression by the common thermometer.

Now p (Barometric height) may be substituted for the weight of the air, and f' for the saturation weight of vapour at t': therefore by the above data f' will be $= \frac{d \times 2880}{30} = \frac{d}{96}$ or, (as d is the object sought) d (or D) $= 96 f'$, at the pressure 30.

This simple enunciation, making D in the direct ratio of f', is unduly criticized by M. Anderson in his elaborate treatise on hygrometry in Brewster's Encyclopedia; but while in reality it will be found closely to agree with the experimental data, and with the subsequent formulæ of others, the new expression deduced from "the laborious investigations" of the critic, turns out to be wholly at variance with experiment, except accidentally at the temperature of the single trial he has himself recorded: his formula (omitting the correction for the barometer) is $D = \left(36 - \frac{D}{10}\right) (f - f'')$ which, when $f'' = 0$, is convertible into

$$D = f \times 36 - \frac{D}{10}$$

making the depression depend on the tension at t, instead of at t'.

M. Gay Lussac's memoir should, I fancy, precede Mr. Anderson's. It was written in 1815, though not published until 1822. The rationale of his formula is explained in these words:—

"Le froid produit (par l'evaporation) est à son *maximum* lorsque le calorique absorbé par la vapeur est égal à celui que perd l'air pour se mettre en équilibre de temperature et de pression avec elle, plus à celui versé sur la surface évaporante par les corps environnans; mais la quantité de ce dernier, lorsque le froid produit n'est que de quelques degrés, est très petite en comparaison de l'autre, et peut etre negligée." If, therefore, on one side the latent heat of vapour (l) and its density (δ) be combined with its weight (f'); these should counterbalance the weight of air $(p - f')$ combined with its capacity (c) and the number of degrees cooled (D or $t - t'$); that is, $f' \delta l = (p - f') (t - t') c$

or, at 30 inches, $f' \times .625 \times 960 = 30 - f' \times d \times .2669$ and

$$D = \frac{2247 f'}{30 - f'},$$

depending as before on f'. With *dry* air, the divisor in this equation should, I imagine, lose $-f'$ altogether, which would elicit the value of d, $= 74.9 f'$; a value lower than Leslie's, but almost exactly agreeing with M. Gay Lussac's own experiments detailed in Table I.

Captain Herbert's formula was founded on the proposition that "when the equilibrium or stationary point of the wet-bulb is attained, the indefinitely small decrements of caloric from evaporation are balanced by the indefinitely small increments arising from conduction and radiation in the equally small moments of time." Now as Messrs. DULONG and PETIT have shewn that the rate at which a body cooled below the temperature of the air (by conduction and radiation) reacquires heat, is proportional not to the simple difference of temperature, but to that difference raised to the 1.233 power; hence it should follow that the amount of evaporation should increase in the same ratio; "but," says he (page 191), "how determine the rate of evaporation? One of the most striking phenomena of evaporation is the cold produced by it; the consequence of the absorption of heat attending the conversion of water into vapour. This depression of temperature must evidently be as the evaporation; or rather the momentary depression will be in proportion to the rapidity of the evaporation. The momentary depression is equal to the momentary increment of heat which would take place were the cooling power of evaporation suspended, and the moistened bulb thermometer allowed to assume the temperature of the air. This is known to be as the 1.233 power of the total depression: the evaporation will then be as the 1.233 of the depression." But the evaporation is (according to DALTON), as the tension of the evaporating surface *minus* the tension of the vapour in the air (= 0 in dry air:) then finally this tension will be as the 1.233 power of the depression: or

$$d\,m = \sqrt[1.233]{f' - f''}$$

m being a co-efficient depending on the latent heat of air and the ratio of the evaporation to the weight and surface necessary to produce a fall of one degree; which Captain HERBERT deduced from the experiments made at Benares. The complete formula, at 30 inches, for dry air becoming

$$\mathrm{D} = \sqrt[1.233]{\frac{\mathrm{L}f'}{6.056}}$$

in which L (proportion of mass of water to the vapour required to be evaporated to produce a fall of 1°) is derived from a table published in the Oriental Magazine, September 1827; it varies from 898 at 40° to 1005 at 90° and 1250 at 1800. The divisor 6.056 would require to be diminished to 5.4 to suit the present experiments, but neither would the formula then agree so well as the more simple one of LESLIE and others. The fact is that the experimental curve is of so simple a nature, that any geometric series of moderate divergence may within limits be accommodated to it by proper co-efficients: thus my own formula was merely an empiric one formed to represent the experimental data of Benares and those of Gay Lussac in the most ready manner, expressing the depressions in terms of the temperature of the air: the former increasing geometrically with arithmetical increments of the latter, I found $d = \frac{t'^{1.275}}{8.91}$; but this does not correspond at all with the higher depressions now ascertained experimentally, though it suits those of the former series. We may, therefore, reject it without further regard: nor need we pause to consider Berzelius' more simple rule, founded, he says, on the experiments of August, Bonenberger *and others,* viz. that the temperature of the wet-bulb is always an arithmetical mean between that of the air and the dew point, or $t'' = 2t' - t$, which, except at certain points of the scale, is utterly erroneous.

We now come to Professor Apjohn's formula, which will be found not to differ essentially from those of Leslie or Gay Lussac. It is $f'' = f' - m\,d$ (at 30 inches pressure) where m is a co-efficient as usual "depending upon the specific heat of air, and the caloric of elasticity of its included vapour," of which the arithmetical value deduced from received data is .01149 or the equivalent vulgar fraction $\frac{1}{87}$ at 50° Farh. Now in the case of extreme dryness assumed for our comparison, $f'' = 0$; therefore $d = 87\,f'$; an expression entirely agreeing in form with Leslie's, but rather smaller in amount, and more nearly, as will be seen, in accordance with the experiments of Tables II and III.

Dr. Hudson arrives, from different premises, at nearly the same method as Professor Apjohn*. He calculates a column of the "relative quantities of heat (Q) necessary to supply vapour of saturation to dry air at each degree of wet-bulb temperature, t', and then finding from experiment at one point ($t_{,} = 61°$) the actual depression (51.124 Apjohn), the depressions at other degrees he assumes to be direct proportionals, or Q (at 61°) : Q' :: 51.124 ; D.

Now it is evident that in this equation, as in most of the preceding, Q (whence D is directly derived) necessarily depends on the aqueous tension, f', affected by the indispensable co-efficient of the latent heat of water, vapour and air, or as Dr. Hudson deduces from Despretz's values, $Q = \frac{1168 - t \times 22\,f'}{448 + t}$†. For

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* Phil. Mag. Oct. 1835, p. 257.

† If the theory which makes the sum of the latent and thermometric heat for gaseous bodies a constant quantity be correct, Dr. Hudson's expression does

ordinary temperatures, Q on an average will be found $= 50\,f'$ and D is assumed from APJOHN's experiments $= \frac{51.124\,Q}{25.9} = 1.9\,Q$; so that by this formula (at 30 inches,) $D = 98\,f'$, nearly; being a little in excess of LESLIE's original formula. This is attributable to APJOHN's single experimental depression assumed as the basis of the whole calculus being somewhat too great.

It cannot be said after the preceding list, that the wet-bulb theory has been neglected. On the contrary, it may be rather feared that the researches of its earliest investigators, particularly those of LESLIE and GAY LUSSAC, have been neglected; for it is certain that their formulæ are nearly as well adapted to the actual phenomena as any that have been since suggested. This cannot be more strikingly exemplified than in the accompanying diagram, (Pl. XXI.) which has been filled up from the preceding data. The abscissæ represent the temperatures *(t)*, and the ordinates the maximum depressions in dry air (D). The experimental determinations are shewn by dots*, and the principal theoretical curves delineated, are distinguished by the name of their authors.

The following table also embraces a comparative view for every ten degrees of temperature, the experimental entries being adapted by interpolation from the observations before set forth.

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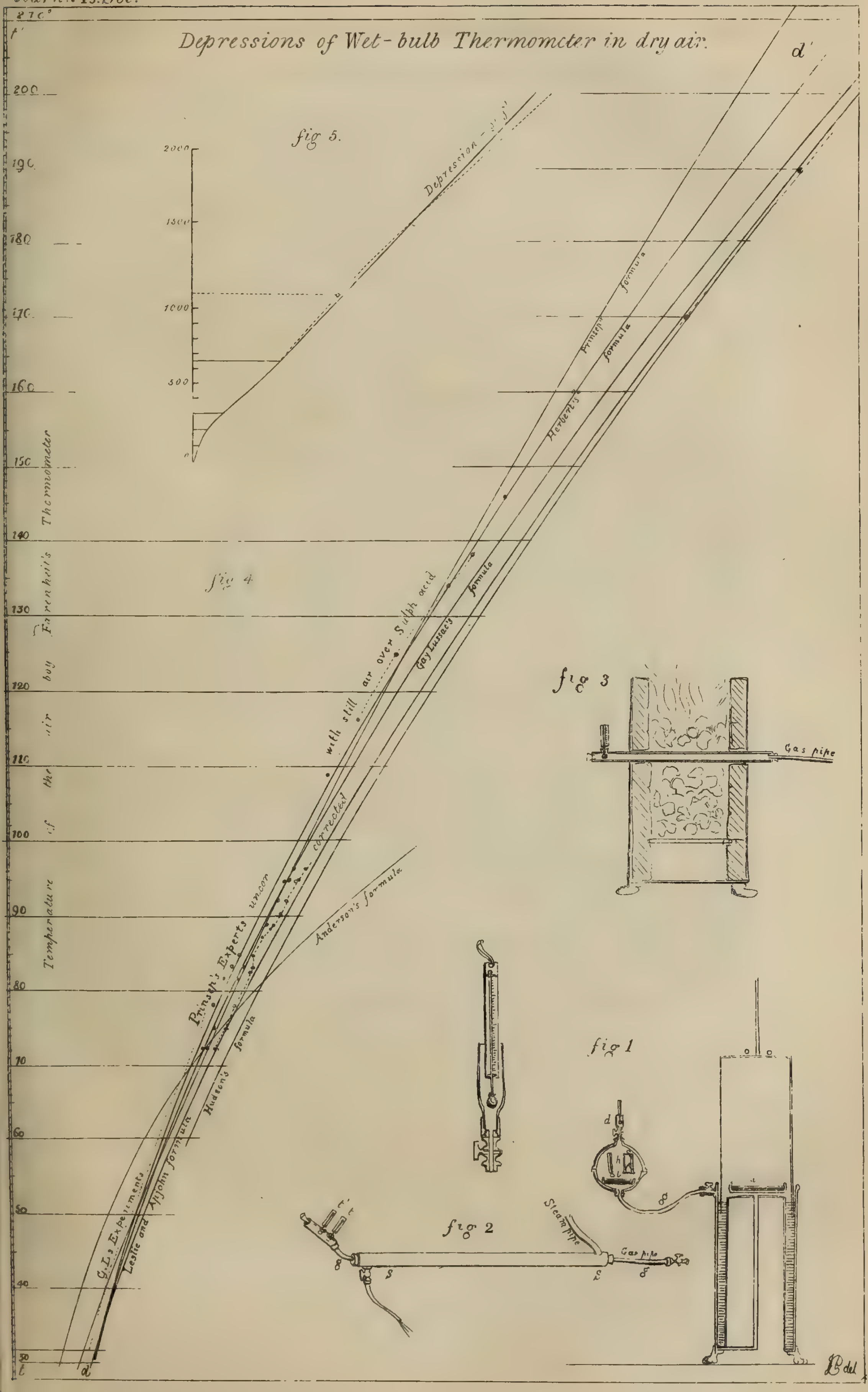
not seem open to objection. The *volumes* of air at different temperature being as $\overline{448 + t}$ directly: the *densities* are as $\overline{448 + t}$ inversely; and for any other pressure $\frac{f}{30}$ the density of air at t will be $\frac{660f}{\overline{448 + t} \times 30} = \frac{22f}{448 + t}$. Further, allowing the atomic theory of volumes, the *density of vapour* at t will be $= \frac{.625 \times 22f}{448 + t}$. Compounding this expression with that of the latent heat of vapour at t which is $1168 - t$ (being 956 at 212°); we have as above the quantity of heat necessary for the vapour of saturation at $t = \frac{\overline{1168 - t} \times 22f'}{448 + t}$. The author has steered clear of what he considers the disputed points, of the *capacity* of air and vapour for heat: but it may be reasonably doubted whether the assumption of the equality of $l + t$ be a whit more tenable.

* In the portion of the curve marked "PRINSEP's experiments," both the uncorrected and the corrected observations are entered; the latter, distinguished by a dotted line passing through them, are alone to be attended to. The corrected places of the sulphuric acid experiments have been omitted, because they are necessarily doubtful. The *flexure* of GAY LUSSAC's curve seems to be the most suitable to experiment, were its ordinates a little increased.



Depressions of Wet-bulb Thermometer in dry air.

Tab. III.—*Comparison of various formulæ for the depression of the wet-bulb thermometer in a current of dry air, with the results of experiment.*

Temperature of the current of dry air.	Temperature of the wet-bulb therm.	Observed depression.	Calculated depression for Bar. 30 inches. Observer's name.	Leslie's formula $D = 96 f'$.	Gay Lussac's form. $D = \frac{2247 f'}{30 - f'}$	Prinsep's formula $D = .0112 t^{1.275}$.	Herbert's formula $D^{1.233} = 156.8 f'$ (nearly.)	Hudson's formula $D = 98 f'$ (nearly.)	Apjohn's formula $D = 87 f'$	Formula adopted for tables $D = 84 f'$.	Error of ditto from observation.
t	t'	D		D	D	D	D	D	D	D	
°	0										
30	20.8	9.2	G.	11.7	9.2	8.6	11.0	..	10.8	10.6	
40	27.3	12.7	G.	14.9	13.1	12.4	13.5	..	14.0	13.6	
50	33.9	16.1	G.	18.6	16.4	16.4	16.7	..	17.6	17.1	+0.1
	33.0	17.0	A.								
60	40.1	19.9	G.	22.9	20.6	20.7	20.0	23.4	21.8	21.3	—0.3
	38.4	21.6	A.								
70	46.0	23.7	G.	27.6	24.9	25.2	24.3	28.1	26.4	25.9	+0.2
	44.9	25.7	P.								
80	..	30.6	P.	32.7	29.7	29.9	28.4	33.2	31.3	30.8	+0.2
90	..	35.5	P.	38.2	34.6	34.7	33.1	38.4	36.5	36.0	+0.5
100	..	40.8	P.	44.0	40.0	39.7	38.2	44.0	42.2	41.6	+0.8
110	..	47.8	S.	50.0	46.0	44.9	43.5	49.0	48.3	47.6	—0.2 ?
120	..	54.1	S.	56.4	52.0	50.2	49.2	56.0	54.5	53.9	—0.2 ?
130	..	60.9	S.	63.1	58.6	55.6	55.1	62.2	61.1	60.5	—0.4 ?
140	..	68.2	S.	70.0	65.5	61.0	61.3	..	68.0	67.3	—0.9 ?
150	..	74.8	C.	..	72.4	66.7	..	..	75.1	74.3	—0.5
160	..	81.3	H.	..	79.4	72.5	..	..	82.3	81.5	+0.2
170	80.0	90.0	P.	..	87.0	78.2	79.8	90.4	89.6	88.9	—0.1
180	80.4	99.6?	P.	..	94.6	84.2	..	..	97.2	96.5	—3.1 ?
190	85.0	105.0	P.	107.0	102.0	91.2	98.	102.0	105.0	104.3	—0.7
200	..	..	..	..	109.5	96.4	..	..	112.0	111.1	
210	..	..	..	..	..	102.4	..	..	120.0	118.	
?	145.0	..	P.	627.	625.	105.	308.	487.	567.	552.	

[The letters in column 4 denote, G. Gay Lussac; A. Apjohn; P. Prinsep; S. experiments tried at Benares, by suspending the wet-bulb thermometer in a half filled bottle of sulphuric acid; these have been augmented 10 per cent. on insertion:—C. and H. Carbonic acid and Hydrogen gas heated in the steam pipe.]

The last line may be looked upon, in some measure, as the test line of the various formulæ: for, the hot current of air from the furnace, we have seen, barely melted lead and boiled mercury; its temperature, therefore, could not much exceed 660 Farh. Let us see what it would be according to the principal formulæ depending upon the aqueous tension at t', which, when $t' = 145°$ is 6.53 inches by Dalton.

Leslie's formula gives $6.53 \times 96 + 145 = 772°$
Gay Lussac's (retaining f') $6.53 \times 95.7 + 145 = 770$
(omitting $-f'$ in divisor) $6.53 \times 782 + 145 = 655$
Hudson's formula gives $487 + 145 = 632$
Apjohn's, ... $6.53 \times 87 + 145 = 702$
Formula deduced from my expts. $6.53 \times 84 + 145 = 697$

Anderson's, Herbert's, and my former formulæ are too much at variance at this high point to be worthy of quotation. The rest agree remarkably well, and it does not materially signify, nor is it perhaps possible to certify which multiplier is to be preferred. Professor APJOHN's has the merit of coinciding precisely at the temperature of 190° with my steam experiment; but for the range of lower and more practical temperatures it is perhaps slightly in excess. The simpler expression of "one-eightieth of the depression = the aqueous tension at t'" would there be nearer the mark; and would be easier of application. From my own experiments I deduced a mean of $D = 84 f'$ with which I constructed the table at the conclusion of this paper, but I must in fairness acknowledge that its preference to Professor APJOHN's rule is nearly evanescent in practice.

§ 2.—*Value of depressions less than the maximum, in centesimal hygrometric tension.*

We are now arrived at the second subject of inquiry, which is in fact of more practical importance than the first, since it includes every observation that can be made in an atmosphere never reduced to a state of absolute siccity.

The simplest condition of the case of *intermediate depressions* would be that assumed by Dr. HUDSON, viz., that the maximum depression being divided into 100 parts, each part should indicate one hundredth of the moisture of saturation at the given temperature, or $D : d :: f' : f' - f''$.

But such a law is not found to prevail in reality: nor is it analogous to the course of nature that it should exist in the case of the wet-bulb thermometer, when the hair-hygrometer and the law of evaporation require different ratios. It is more consonant with theory*, as it proves to be with practice, that the tendency to evaporation, and the cold consequent upon it, should increase in a geometrical ratio to the dryness of the air.

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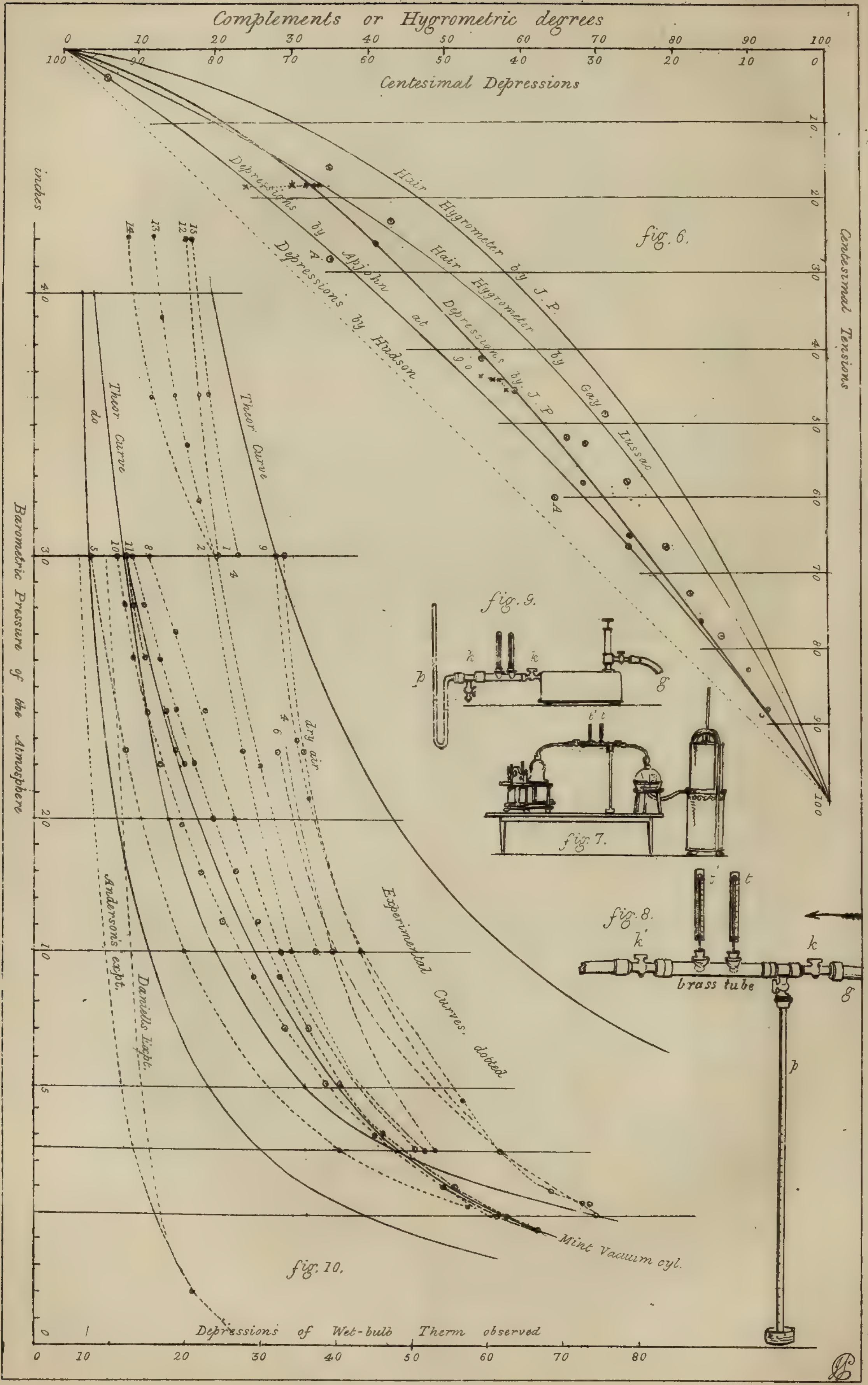
* The depressions will, *ceteris paribus*, be less, the more aqueous vapour is previously contained in the air, because the specific heat of a given volume of vapour being .529 (or .847×.625) while that of air is .267, the specific heat of any mixture of the two must exceed that of air alone. But the curvature imparted to the line of depressions from this cause may easily be shewn to be trifling. Thus at the temperature of 80° where $f = 1.00$ inch; the capacity of dry air being c, that of moistened air will be $\frac{c \times \overline{p - f''} + c' \times f''}{p}$; whence, calling $c = 1$, for saturated air we should have the specific heat 1.053; and for half-saturated air, 1.031; and the depressional degrees at those points will be inversely so much less than those at the dry extremity of the curve. Were the other agents easily evaluated, we might through this means verify the specific heat of aqueous vapour.


Complements or Hygrometric degrees
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
Centesimal Depressions
Centesimal Tensions
10 20 30 40 50 60 70 80 90 100
Hair Hygrometer by J. P.
Hair Hygrometer by Gay Lussac
Depressions by J. P.
Depressions by Apjohn at 90
Depressions by Hudson
A
fig. 6.
fig. 9.
p
k
k
g
t' t
fig. 7.
fig. 8.
t' t
k'
k
brass tube
g
p
inches
Barometric Pressure of the Atmosphere
40
30
20
10
5
0
14 13 12 15
Theor Curve
do
Theor Curve
5 10 11 8 2 1 4 9
4 6 dry air
Experimental Curves. dotted
Anderson's expt.
Daniells Expt.
Mint Vacuum cyl.
fig. 10.
Depressions of Wet-bulb Therm observed
0 10 20 30 40 50 60 70 80

Before proceeding to detail the experiments directed to the elucidation of this point, it may be as well, as we have already become acquainted with the theoretical expressions of other authors for the *maximum*, to see how they also bear upon the *intermediate* depressions.

The formula of M. GAY LUSSAC makes no provision for aught but the maximum depression; but the omission may be readily supplied on the same simple principle as has been adopted by Professor APJOHN; namely, by the addition of $-f''$, the aqueous tension at the dew-point, to f': thus, by the latter author, in all cases $d = 87 f' - f''$.

At first sight, this would seem a simple arithmetical ratio, like Dr. HUDSON's, but inasmuch as the tensions *(f)* are themselves in geometrical ratio to the temperature *(t)*, the same parabolic curvature will extend to the centesimal depressions; or $f' - f''$ will follow some low power of $t - t'$.

Captain HERBERT's rule has the same happy introduction of f''. We have therefore but two theoretical enunciations to put to the test of comparison with experiment: for which purpose I will now bring forward such evidence as I have accumulated. In this branch of inquiry materials are so numerous in my registers kept at Benares and Calcutta, that it becomes expedient to gather selected data into groupes adapted to elucidate various points of the hygrometric scale. Moreover, as unity, or the maximum depression, varies in amount at each temperature, all observations must be brought to common centesimal terms before they can be compared in the manner which is best adapted to give a quick perception of the relation of such phenomena; namely, by a diagram, as in Pl. XXII. First, then, to enumerate the data afforded by method 5, or comparison with the dew-point, of which, in addition to my Benares observations, I have profited by the presence of an American ice-house on the banks of the Húghlí to collect an accurate series made thrice per diem in the hottest period of our Calcutta year.

TAB. IV.—*Comparison of intermediate Depressions with aqueous tensions, ascertained by the dew-point method, at Benares.*

Number of observations agreeing closely in their respective particulars.	Temp. of air. t °	Wet-bulb. t' °	Dew-point. t'' °	Centesimal tension. $f'' \div f$	Depression. $t - t'$ or, d	Complement cent. depn. $\frac{D-d}{D}$	Tabular centesim. tension deduced.	Error.
7 Obs. mean,	85.0	81.5	79.4	.83	3.5	89	.84	+01
12 Obs. ditto,	87.5	81.8	78.7	.76	5.7	83	.76	0
12 Obs. ditto,	90.0	80.5	75.7	.65	9.5	74	.64	—01
6 Obs. ditto,	94.0	81.0	73.2	.52	13.0	66	.54	+02
6 Obs. ditto,	92.5	75.5	64.5	.41	17.0	55	.40	+01
13 Obs. ditto,	88.2	67.3	42.9	.23	20.9	43	.26	+03
8 Obs. ditto,	92.6	68.3	36.4	.16	24.3	35	.20	+04

Second series, from observations in Calcutta.

	t	t'	t''	$f''\div f$	d	$\frac{D-d}{d}$	*Tab.*	*Err.*
6 Obs. open air,	82.1	79.4	78.1	.88	2.7	92	.88	0
6 Obs. ditto,	84.6	79.9	76.7	.78	4.7	86	.80	+02
9 Obs. ditto,	85.6	79.7	75.5	.73	5.9	82	.75	+02
15 Obs. ditto,	87.7	80.2	74.6	.66	7.5	79	.70	+04
2 Obs. ditto,	96.0	85.6	78.3	.58	10.4	74	.64	+06
3 Obs. ditto,	93.8	82.9	71.2	.49	10.9	71	.60	+11 ?
4 Obs. ditto,	87.3	76.4	67.3	.53	10.9	68	.58	+05
3 Obs. ditto,	97.1	80.8	71.8	.45	16.3	59	.45	0
6 Obs. ditto,	97.3	73.6	55.5	.26	23.7	41	.26	0
1 Steam pipe,	19.0	92.5	74.3	.04	97.5	6	.04	0
3 Vacuum-pipe	92.8	80.8	74.8	.58	12.0	68	.57	—01
Third series, extracted from other observations.								
7 Obs. by *Herbert* on river Ganges,	91.4	82.1	78.1	.66	9.3	74	.65	—01
6 Obs. by *Apjohn*,......	70.0	60.8	54.5	.60	9.2	64	.52	—08
4 Obs. *ditto*, (heated air,)	93.2	69.0	53.7	.28	24.2	35	.22	—06

In the following series the air was dried to two fixed points of hygrometric tension by means of sulphuric acid, of which the drying power was known beforehand by the table which I published, from careful experiment, in my note on the hair hygrometer before alluded to; but I preferred verifying those determinations by fresh measurement of its barometric tension, in the mode I had adopted to correct the tables of aqueous tension during the past year; namely, by moistening a barometer tube with the acid solution, and mounting it in the ordinary manner. The daily readings registered in my monthly tables for May-June afforded a more accurate average than a cursory trial could have yielded; but the result was in perfect accordance with my former determination*.

Fourth series—current of air partially dried.

Number of observations in similar circumstances.	Temp. of air. t	Wet-bulb. t'	Known cent. tension.	Hair Hygrom.	Depression. $t-t'$ or, D	Complement cent. dep. $\frac{D-d}{D}$	Tabular centes. tension.	Error.
2 Obs. with gasometer current, Sulph. acid, 1.344, ...	° 90.2	° 75.3	.45	75	° 14.9	58	.45	0
2 Obs. ditto, ...	87.2	72.1	.44	74	15.1	56	.43	—01
2 Obs. ditto, ...	90.3	74.4	.44	74	15.9	56	.43	—01
1 Obs. ditto, ...	96.4	79.4	.44	74	17.0	57	.44	0
1 Obs. ditto, ...	94.0	76.6	.43	73	17.4	54	.40	—03
2 Obs. sulph. acid, 1.48, ...	88.8	65.2	.18	43	23.6	33	.20	+02
1 Obs. ditto, ...	87.7	61.1	.18	43	26.6	24 ?	.12	—06
1 Obs. shorter tube,	84.4	62.0	.18	43	22.4	32	.18	0
2 Obs. brass tube,..	87.8	64.3	.18	42	23.5	30	.17	—01

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* It will be seen by the Meteorological Register for May 1836, that pure sulphuric acid caused the barometric column to be higher even than a boiled tube. This must be attributed to capillarity, which is negative with mercury, but acts in an opposite sense with acid or water. No allowance is made for capillarity in my registers.

On inspection of the columns of complementry centesimal depression and centesimal tension in all the foregoing tables, the constant excess of the former is their first predominate feature; whence the certain conclusion that the ratio is not *direct*. But to arrive quicker at a conclusion of what it may be, let us view the position of the whole series in diagram 6, Pl. XXII. Here the base line designates the hygrometric tensions $f'' \div f$ and the ordinates denote the corresponding centesimal depressions $\overline{D - d} \div D$. If amid such a straggling and scattered nebula it be allowable to trace a normal line, the curve D *d* will have a preference over any other. Pursuing its dubious course, it passes through the two principal test groupes, upon which more dependence ought to be placed than upon isolated comparisons with the dew-point in still air. Now this line D *d* nearly coincides with the curve I suggested in 1829, from my Benares experiments, making H (or $f'' \div f$) follow the ratio of $\overline{D - d}^{1.5}$; or, calling $D = 100$, $H = \frac{\overline{D - d}}{100}^{1.5}$; in other words, the *centesimal tension* is as the difference of the actual and the maximum depression raised to the 1.5th power; a form obviously very convenient to be worked by logarithms. This formula has been used for constructing my general table; and its errors may be judged of by the last two columns of the preceding experiments: but it need by no means supersede the elegant formula $d = 87\, f' - f''$ when the table is not at hand. The curve corresponding to the latter formula at 90° is also entered in fig. 6. At lower temperature it will have less flexure.

On the same diagram I have traced the curve of the hair-hygrometer indications, both according to Gay Lussac's data and those of my original plate in Brande's Journal, on purpose to shew that the *depression curve* passes between the two near the summit:—it was hence I derived the rule for correction of the rough maximum depressions, (Table I. II.) by taking it in the direct ratio of the hair-hygrometer indications: and the near accordance of the maxima so deduced, with the observed maxima in dry air, is an additional testimony in favor of the assumed parabolic curve.

It seems an unmerciful increase of the tax upon my reader's patience to extend this train of comparison further: yet it would be hardly fair to omit any thing that can tend to elucidate the subject or assist future investigation: I will not, therefore, forego, through a false and unphilosophical delicacy, the insertion of an abstract I had prepared for my own satisfaction, of three years' comparative deductions from the wet-bulb and hair-hygrometer. It detracts somewhat from its value, that a constant index error of 4 degrees has to be substracted from the readings of the hair-hygrometer during the period in question. This I only discovered on checking all the instruments, as is my custom, before commencing the present experiments; but the hygrometer has been untouched during the interval, and as its scale embraces the 100 degrees with as much sensibility as when it was constructed in 1825, there can be no hesitation in making the required correction throughout. The extreme points of this instrument should indeed be verified at least once in a year; as the index point is, from its delicate construction, easily shifted 2 or 3 degrees.

TAB. V.—*Comparison of the monthly averages of the Wet-bulb depression, and the Hair-hygrometer, for 3 years in Calcutta.*

	At 10 A. M.			Tension,		At 4 P. M.			Tension,	
	Temp.	Dep.	Hyg.	by Dep.	by Hyg.	Temp.	Dep.	Hyg.	by Dep.	by Hyg.
	°					°				
Jan. 1833	68.0	8.4	81	.55	.61	72.4	11.6	74	.47	.49
1834	67.5	6.4	83	.64	.64	71.1	9.2	76	.53	.52
1835	67.8	8.0	80	.56	.59	70.7	11.5	70	.42	.43
Feb... 1	74.0	8.2	82	.60	.63	78.7	12.7	74	.44	.49
2	74.0	7.3	86	.64	.70	77.8	11.6	77	.48	.54
3	74.3	6.0	87	.70	.72	76.6	10.2	76	.52	.52
Mar... 1	83.5	9.8	81	.59	.59	89.2	17.3	66	.37	.43
2	82.3	7.5	86	.67	.68	86.7	12.2	76	.52	.52
3	79.8	8.3	85	.63	.66	83.6	13.0	70	.47	.44
April, 1	87.5	6.2	88	.75	.74	91.6	10.8	79	.60	.57
2	86.5	8.8	84	.65	.67	93.2	13.8	75	.52	.51
3	84.6	7.6	86	.68	.70	88.1	12.7	75	.52	.51
May, . 1	87.5	6.1	91	.75	.80	90.0	8.2	86	.67	.70
2	90.7	7.9	86	.69	.70	94.6	10.9	80	.58	.59
3	86.8	6.5	89	.74	.76	88.3	7.5	86	.79	.70
June, . 1	90.5	6.4	88	.75	.74	92.8	8.1	82	.70	.66
2	87.0	4.8	91	.80	.80	87.8	6.1	90	.75	.78
3	86.1	5.6	87	.76	.72	87.4	6.9	85	.72	.68
July, . 1	86.3	4.0	91	.83	.80	87.9	4.6	90	.83	.78
2	86.6	5.1	91	.80	.80	88.0	6.0	90	.76	.78
3	82.7	4.0	88	.77	.74	85.3	4.8	88	.80	.74
Aug... 1	85.0	4.1	92	.82	.82	86.8	4.9	89	.75	.76
2	85.1	4.2	92	.82	.82	86.7	5.3	91	.78	.80
3	84.0	4.0	92	.82	.82	85.0	4.3	91	.81	.80
Sept.. 1	86.3	4.4	91	.76	.80	88.3	5.5	88	.82	.74
2	85.9	4.9	92	.75	.82	86.4	5.9	91	.76	.80
3	83.7	4.8	91	.80	.80	85.0	6.8	89	.71	.76
Oct... 1	85.2	5.6	87	.76	.72	86.8	7.6	83	.69	.65
2	82.9	4.0	83	.82	.84	83.9	5.0	91	.79	.80
3	83.3	6.8	87	.71	.72	85.1	9.3	82	.61	.63
Nov.. 1	79.	6.9	84	.69	.66	82.1	10.1	77	.57	.54
2	79.2	7.5	85	.66	.68	79.4	10.1	78	.55	.56
3	75.6	7.7	85	.64	.68	77.9	10.0	79	.55	.57
Dec.. 1	71.7	5.8	85	.70	.68	74.3	7.2	82	.65	.63
2	72.4	6.1	87	.67	.72	75.7	9.0	81	.57	.61
3	69.8	6.1	84	.68	.66	72.0	8.9	78	.55	.56
Means,	81.2	6.1	86.8	.71	.72	83.8	8.9	81.5	.63	.63

The actual tension of vapour in inches, found by multiplying DALTON's maximun tension of vapour at *t* by the percentage here given, is, at 81°.2 = 1.040 × .71 = .738 ; at 83°.8 = 1.128 × .63 = .711 (or .716 at 81°.2) being at the two periods of the day, on an average, very nearly equal; though, relatively, the air is much drier in the afternoon.

A similar comparison to that afforded by the above table would have been published with my journals for 1825-6 in the Philosophical Transactions for 1827, had the registers been allowed to stand as they were; but the columns of aqueous tension were struck out, although from the elaborate care I had taken in valuing the degrees of my hair hygrometer they were entitled to some reliance. It is, however, not worth while to republish them, as the wet-bulb instrument was then situated outside and the hair hygrometer inside the house*, and the two columns are not strictly comparable. One little table, however, deduced from four years' daily experiments at Benares, which was also suppressed at home, I think likely to prove useful, while it bears directly on the wet-bulb theory, and exemplifies the truth of the assumption of its immediate dependence on f'. This table shews the actual evaporation in depth per month, as measured by a small evaporameter suspended in the open air, for the opposite extremes of the year. The instrument is described in the fifteenth volume of the *Asiatic Researches*. I have collected on the left hand the observed quantities, and have now inserted on the right the theoretical numbers which should express the ratio of evaporation. The results are even more satisfactory than could have been anticipated; and lead to the following very simple rule to find the amount of evaporation roughly in inches per diem. "Multiply the aqueous tension at the wet-bulb temperature by the observed depression in degrees, and divide by 34." Omitting the latter operation, the product will express in round terms the evaporation per month in the open air, or in a moderate breeze.

TAB. VI.—*Rate of Evaporation and simultaneous depression observed at Benares.*

Months.	Year.	Temp. of air. t. °	Wet-bulb. t' °	Depression. d °	Obsvd. Evaporation per month inches.	Ditto per diem inch.	Aqueous tension, f'.	Depression × tension, $d \times f'$.	Calculated daily evaporation, $\frac{d \times f'}{34}$
April and May,	1823	88.0	68.9	19.1	13.9				
	1824	93.1	71.8	21.3	11.9				
	1825	92.3	74.2	18.1	14.7				
	1826	90.4	69.8	20.7	15.1				
	Means	91.2	70.9	20.3	13.9	0.463	0.748	15.18	0.447
March,	1823	79.8	62.0	17.8	8.7				
	1824	81.4	66.5	13.8	6.7				
	1825	75.1	64.7	11.4	4.0				
	1826	80.8	63.4	16.4	9.8				
	Means	79.4	64.1	15.3	7.3	0.243	0.599	8.16	0.240

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* The Calcutta Oriental Magazine, 1827, contains the whole paper.

							f'	$d \times f'$	$\frac{d \times f'}{34}$
July and August,	1823	80.5	78.2	2.3	2.3				
	1824	85.6	82.1	3.5	2.6				
	1825	86.9	81.3	4.6	4.4				
	1826	84.4	80.8	3.6	3.6				
	Means	84.4	80.6	3.8	3.2	0.107	1.020	3.88	0.114
December and January,	1823	60.1	55.7	4.4	2.3				
	1824	61.8	56.6	5.2	4.0				
	1825	63.5	58.3	5.2	5.6				
	1826	63.8	54.9	8.9	3.1				
	Means	62.3	56.3	6.0	2.5	0.085	0.462	2.77	0.081
					per. an.				
The whole twelve months,	1823	76.4	68.1	8.3	65.6				
	1824	80.0	71.2	8.8	60.5				
	1825	80.0	71.1	8.9	67.1				
	Means	78.9	70.1	8.7	64.4	0.179	0.729	6.34	0.186
			permonth		5.37				

I have, as yet, had no opportunity of applying the principle ascertained from this table, to the circumstances of other places*.

§ 3.—*Influence of the Barometer on the Wet-bulb depression.*

All philosophers agree in rating the influence of atmospheric pressure on depression as inversely proportional to the height of the barometer; so that when the depression under a pressure of 30 inches is known, it may immediately found for any other pressure by multiplying d into $\frac{30}{p}$, p being the observed height of the barometer.

That the evaporation increases with diminution of pressure nearly in the above ratio, has been proved by various experiments; and it might confidently be anticipated, from the necessary connection between the evaporation and the refrigeration, (as exemplified in the concluding table of my last section,) that the same law would prevail in the depressions: but the only two experiments directed to this point that I am acquainted with, lead to an opposite conclusion. These were cited in my former paper: but as they are not accessible to many readers, I will here repeat them. Mr. DANIELL's experiment will be found in Jour. Roy. Inst. XVII., and Mr. ANDERSON's in BREWSTER's Cyclopedia, Art. Hygrometry.

Barometric pressure.	Ratio.	Evaporation in grains by Daniell.	Depression of wet-bulb by Daniell.	Increment.	Depression of wet-bulb by Anderson.	Increment.
30.4	1	1.24	9	0	5	0
15.2	$\frac{1}{2}$	2.97	12	+3	9	+4
7.6	$\frac{1}{4}$	5.68	15	+3	13	+4
3.8	$\frac{1}{8}$	9·12	18	+3	18	+5
1.9	$\frac{1}{16}$	15.92	21	+3		
.9	$\frac{1}{32}$	29.33	24.5	+3.5		
.5	$\frac{1}{64}$	50.74	26	+1.5		

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* The tables now published by the astronomer at Madras will afford good data; but his mode of measurement must be first known, as his evaporations seem double of my own.

Now in these instances the evaporation certainly followed the inverse pressure law; but the depression was made to receive only a constant arithmetical increment for each geometrical decrement of the pressure; in accordance with which I assumed that the proper correction for variation of pressure should be $d\sqrt{\frac{30}{p}}$ rather than $d\frac{30}{p}$; and even this would require a different co-efficient to make it suit the two cases quoted above. Under such an uncertainty as to the real amount of this important correction, I was induced to direct a fresh series of experiments to this particular object; and as my results differ greatly from what has preceded, it is incumbent on me to describe my process a little in detail.

I first prescribed to myself the necessity of working with a current of air as similar as might be to that of the maximum series, as without such a precaution it would be impossible to ensure the permanent hygrometric status of the air in contact with the wet-bulb. The bell glass of an air-pump, under which I imagine the experiments of Daniell and Anderson to have been conducted, could not possibly fulfil this indispensable condition, since a partial halo of moisture would encircle the bulb of their thermometer;—nor do they appear to have used a hair hygrometer to inform them how far this might be the case. Mr. Daniell it is true had a dew-point instrument fitted into the side of the glass receiver, but for slight aqueous tension this instrument becomes wholly useless. The extent to which his air was dried can be calculated pretty well from his own datum that the depression at 50° was nine degrees, which by my table would indicate centesimal tension ·30: or by Apjohn's formula $\frac{.263-(9\div 87)}{.357} = \cdot 42$ in the latter case requiring a cold of 8 degrees, and in the former of 16, below the freezing point to produce deposition.

But to return to my own experiments:—

In place of the short open glass tube connected with the gasometer and glass balloon in which the wet-bulb was before exposed to the current of air, (fig. 1,) a thin horizontal brass tube (fig. 7) was substituted, having two lateral apertures for the admission through corks, air-tight, of the dry and wet thermometer bulbs (t, t'). From the same brass tube descended a glass barometer tube (p) into a reservoir of mercury, similar to the gage of an air-pump, for marking the actual pressure close to the thermometers. The other end of the tube was conducted by a flexible pipe F to the receiver of an air-pump, where a continual vacuum could be kept up by pumping without intermission during the course of an experiment.

and by manœuvring the stopcocks *(k, k')* at the two ends of the brass tube, the pressure could be maintained at any point, and the draft of air regulated until the temperature of the wet-bulb had been satisfactorily ascertained.

Finding that the labour of working the pump was rather irksome in a climate of 95°, I afterwards availed myself of the vacuum engine of the coining-press room in the Mint to relieve me from this duty. In the pipe leading from the twelve recoil-pumps of the presses a vacuum of about (or rather 30—27) inches is constantly maintained by the steam engine, so that by adapting the tube F to this with a stopcock, I was enabled to regulate the pressure, and prolong each interval with the utmost ease and comfort.

It will be seen from the table of experiments below, that *by employing a current of dry air* the freezing point was readily attained under a pressure of 7½ inches, while the dry thermometer, only one inch from it, marked 92° : whereas all who have tried Leslie's process for freezing have found it exceedingly difficult in the hot weather of this country to produce ice with a vacuum nearly perfect. The reason has been already explained : in the latter case the partially moist atmosphere arrests the progress of refrigeration ; whereas in the latter, the vapour rising from the evaporating surface is continually removed ;—it is, in fact, like sitting under a punkah or without it, an illustration that requires no comment to an Indian reader ! Of such influence is the motion of the air in the experiment, that, as will be seen presently, a cold *much below the freezing point* may be attained under a pressure of 4½ inches, *with common air at* 92° *containing six-tenths of its vapour of saturation* (dew-point = 75°) and without the aid of sulphuric acid, or any other artificial means of previously drying it ! This unexpected result opens a wide field for speculation as to the possibility of modifying the apparatus of Leslie for the artificial production of ice ; and I hope, when leisure permits, to resume the thread of this collateral and highly interesting discovery. The nature of the problem teaches us *à priori*, that if a temperature of 20° can be attained under a pressure of 4½ inches, the cold at two inches ought to be many degrees below zero of Fahrenheit's scale !

Out of four experiments made with the air-pump, and eight with the Mint vacuum engine, it will be sufficient, after quoting the numerical results of the whole, and referring to the accompanying diagram (Pl. XXII. fig. 10.) for a comprehensive view of their general bearing, to select two or three of the most regular examples for analytical discussion.

Tab. VII.—*Depressions under diminished pressure.*

	Temp. of air.	Hyg. tens.	Temp. of wet-bulb, under a pressure of 30.	22.5	15.	7.5	6.0	5.5	5.0 in.
	°		°		°	°			
1. Expt. with air pump, air dried by Sul. Ac. 1.48,	84.0	.18	61.0	..	56.0	48.			
2. Ditto, corks fitted closer,	84.7	.18	..	..	51.0	..			
3. Brass tube, better fitted,	84.4	.18	62.0	57.0	50.3	32.0			
4. Ditto, careful expt...	87.8	.18	64.3	55.0	49.0	35.0			
5. Common air, in Mint vac. tube; dew-point 79°.5,	88.5	.75	81.3	76.4	69.0	48.0	..	32.0	
6. Partially dried, hair-hyg. in balloon av. 34, ..	92.1	.12	64.?	60.1	52.9	31.0	24.0	20.0	18.0
7. Nearly dry air ; hyg. 1°,..	91.0	.00	58.3	54.4	48.7	30.0	20.4	18.5	
7½. Partly dried ; hyg. 12 ? ..	91.0	.03 ?	..	65.	53.9	..	25.7	20.0	
8. Hygrom. variable, av. 20..	93.2	.05	79.1	75.1	59.6	..	..	..	
9. Dry air ; hyg. 2°, ..	92.0	.01	59.5	63.2	56.3	38.5	..	26.4	20.0

The last experiment is evidently affected with some accidental error, since the depression is *less* at 22.5 inches than at 30. I imagine the external air was admitted through an unobserved leakage of the tube, or a drop of water may have fallen in the tube, and thus moistened the air before it reached the wet-bulb.

I now detached the gasometer and balloon, and admitted the air of the room directly into the tube at stopcock *k* (fig. 8) keeping up a prolonged current at intervals of every two inches of pressure from 30.0 upwards to 5 inches, and then descending in the same manner : taking care to wet the thermometer from time to time as its water evaporated. In ascending the scale I regulated the pressures in the barometer-gage principally by manœuvring the stopcock (*k*′) next to the vacuum pipe, the orifice at *k* remaining constant : whereas in descending, I allowed *k*′ to remain untouched while I brought the gage to the desired point by gradually opening the outer stopcock *k*.

The effect of this will be understood on viewing the apparatus : the current of air was considerably stronger in the last case than in the first, and in consequence the depressions are somewhat greater. To this it must be added, that in the ascending scale the depressions will tend to lag below their full amount, while in descending they will err in an opposite sense ; all of which is well exhibited in dotted curves numbered 10, 11 of diagram 10. The mean of the two series (marked by a plain line on the diagram) may be assumed as a good foundation for the analysis we have proposed.

Experiments 10 *and* 11, *on depressions under diminished pressure.*

Temperature of the room 92°.2 ; dew-point 74°.8 = centesimal tension .58
Hair-hygrometer, 79 = ditto .57

Barom. pressure inches.	*Ascending series.* Temp of air.	Wet-bulb. 1	Wet-bulb. 2		*Descending series.* Wet bulb. 3	Wet-bulb. 4	Temp. of air.	Depression ascending.	Depression descending	Mean depression observed.	Calculated depression. $d \times \frac{30}{p}$
	°	°	°		°					°	
30	92.7	80.4	82.0	rewetted)	80.5		93.0	11.7	13.0	12.0	12.
28		79.7	80.8		79.2			12.6	14.3	13.1	12.9
26	92.9	78.0	80.0	rewetted	76.8	79.2		13.9	15.5	14.6	14.0
24			77.8		74.7	75.2		15.0	18.0	17.0	15.0
22	92.7		75.4	(rewetted	72.4	73.8		16.4	20.4	19.1	16.4
20			73.0			70.2		19.8	23.3	21.5	18.0
18			70.3			66.9		22.5	26.6	24.5	20.0
16			67.7			64.2		24.2	29.3	26.8	22.5
14	93.0		64.0			61.2		29.	32.3	30.6	35.7
12			60.0			57.4		33.	36.1	34.5	20.0
10			54.9	(rewetted	54.6	53.8	93.2	38.1	39.7	38.9	36.0
8			48.3		47.3		93.2	44.7	45.9	45.3	45.0
6			38.0		38.8		92.5	55.0	53.7	53.1	60.0
5			31.0		30.8		91.6	62.0	60.8	61.4	72.0
4.4				rewetted	23.7		89.8		66.1	66.1	81.8

At the first glance towards the final columns of this table, one might at first be led to exclaim, upon the wonderful accordance between theory and fact! The ascending series, especially, agrees exactly with the calculation in several points, and does not diverge materially until the pressure falls to six inches, far beyond the reach of any likely contingency within our observance.

But all this seemingly agreeable coincidence is, in a measure, delusory. The effect is compounded of two different influences—1, the rarefaction; and 2, the diminution of humidity which is consequent thereon. We know from our second section of experiments how to appreciate this latter disturbing cause, and so isolate the reduction of temperature due to the diminished pressure alone; but the prior experiments give us an opportunity of estimating it in a more direct manner. Thus, taking experiment 7, we have the following data: the temperature being 91°. Fahrenheit. The fourth column contains the hypothetical depressions on the supposition of the inverse-pressure ratio.

Barometrical pressure inches.	Depression in dry air. D	Increment observed. D—d	Theoretical depression. $d \times \frac{30}{p}$	Increment $d + \frac{30}{p} - d$	Calculated co-efficient.
	°	Δ		δ	Δ ÷ δ
30.0	32.7		32.7		
27.5	35.6	+ 2.9	43.6	+ 10.9	.27
15.0	42.3	+ 9.6	65.4	+ 32.7	.29
7.5	61.0	+ 28.3	130.8	+ 98.1	.29
6.0	70.8	+ 30.1	165.5	+ 132.8	.23
5.5	72.1	+ 39.4	176.5	+ 143.8	.27
5.4	72.8	+ 40.1	179.8	+ 147.1	.27

The rate of increment observed, it will be remarked, here invariably falls short of the calculated rate in the fifth column, but it bears always the same proportion to it, about one-third; as shewn in the sixth column: therefore in this example the law of the inverse pressures holds good relatively, but it requires a co-efficient to reduce the absolute amount. Thus, the maximum depression in dry air at any pressure will, by the experiment, be equal to $d + .27\left(d\frac{30}{p} - d\right)$ instead of $d + \left(d\frac{30}{p} - d\right)$ (or simply $d\frac{0}{p}$). I will not seek to enquire the cause of this deviation from theory; or whether it be peculiar to the form of apparatus I employed; or whether the effect will be constant under all circumstances:—I will merely suggest that the supply of heat from extraneous sources—the brass tube (only half inch diam.) radiation, &c. could not fail to reduce the cooling effect of the mere current of air; and here we have the measure of their united disturbing power, which it is satisfactory to find constant throughout.

Let us now see whether the same constancy can be traced in the more elaborate experiment with common air (10-11.) The first thing necessary is to calculate the percentage of moisture for each step. Now, as under 30 inches the centesimal tension was found to be ·58 by the dew-point, and as no source of fresh supply was at hand, the tension at any other pressure should be directly as the pressure, or inversely as the volume; since it is evident that a double space, for instance, will require twice as much aqueous vapour to bring it to a given state of humidity; the aqueous tension, therefore, will be $·58 \times \frac{p}{30}$ for this series of experiments. Again, from our table of depressions, (from the diagram or from the formula) can be obtained, with the reading at these variable states of humidity, the depression either in dry air or in air of the initial tension ·58. I have, in fact, given both in the following table, and have set in the three last columns the calculated depressions by the expression just found of $d + .27\left(\frac{d\,30}{p} - d\right)$.

Tab. VIII.—*Experiment* 10-11, *reduced to a constant hygrometric state.*

Barometer. inches.	Centes. aqueous tension calc. $H \times \frac{p}{30}$	Tabular centesimal depression corresponding T	Observed depression variable aq. tens. d	Deduced depression for aq. ten. .58 $d \times \frac{32}{T}$	Deduced depression for dry air, $D = d \times \frac{100}{T}$	Calculated depression for variable aq. tens. of second column.	Calculated depression for aq. tens. .58	Calculated depression for dry air.
			°	°	°	°	°	°
30	.58	32	12.0	12.0	37.5	12.	12.0	37.5
28	.54	34	13.1	12.2	38.2	13.1	12.3	38.2
26	.50	37	14.6	12.5	39.0	14.5	12.6	39.1
24	.46	42	17.0	12.8	40.1	17.0	12.8	40.1
22	.42	44	19.1	13.8	43.3	18.2	13.3	41.4
20	.39	47	21.5	14.7	46.0	20.1	13.7	42.8
18	.35	50	24.5	15.7	49.0	22.3	14.3	44.6
16	.31	54	26.8	15.9	49.8	25.6	15.0	47.4
14	.27	58	30.6	16.9	52.7	28.8	15.9	49.7
12	.23	62	34.5	17.8	55.5	33.2	17.1	53.5
10	.19	66	38.9	18.6	58.2	39.2	18.7	58.9
8	.15	72	45.3	20.2	63.3	49.4	19.4	69.6
6	.11	76	53.1	22.3	69.8	63.0	25.7	80.4
5	.096	78	61.4	25.1	78.5	71.0	29.1	91.0
4.4	.085	79	66.1	26.7	83.5	78.0	34.8	99.6

With exception of the four lowermost entries, the three middle (or observed) columns of this table accord wonderfully well with the three last, which are calculated by the formula above given multiplied into T, (the tabular cent. dep.); which is variable in the first of them, (that of the experiments;) is equal to ·32 for the case of humidity ·58; and is of course = 0 for the final case, of extreme dryness. Were we to suppose that the dryness of the air did not mount higher than ·18 (second column) from some unperceived cause, the calculated depressions would suit equally well from beginning to end; and it must be remembered that any disturbing force will be much more felt in the low pressures. Moreover, it can hardly be expected that the depression should continue to follow the same law, after the evaporating surface has congealed into ice. Had the ascending series of depressions only been used, instead of the mean, the accordance would have been greater towards the middle of the scale.

It is hardly necessary to analyse any more of the present series, after ascertaining that the same co-efficient is equally applicable to dry and wet air. We may therefore proceed at once to the conclusion, that *the depression of the wet-bulb thermometer, ceteris paribus, varies inversely as the barometric pressure, the actual variation being for every case twenty-seven hundredths of the calculated variation.*

§ 4.—*Depressions under augmented barometric pressure.*

It would perhaps have been better to have preceded the last enunciation, by a description of the experiments included under this head, since they obviously form part of the same series, and must be governed by the same law. They need not detain us many minutes.

The modification of apparatus now employed is depicted in fig. 9. Between the gasometer and the brass tube furnished with the two thermometers was introduced a condensed air blow-pipe; while at the other extremity near the discharge cock *k'*, was adapted a syphon barometer capable of shewing an increase of pressure up to + 12 inches. By keeping up the action of the pump with the discharge cock more or less open, a current of condensed air could be maintained at any pressure until the readings of the wet-bulb became stationary; for, as before stated, it was upon the current only that reliance could be placed; and my endeavour was always to maintain the same rapidity in the passage of the air, although small variations in this particular do not, and ought not, to produce any sensible error.

Not having used a hygrometer in this series, I trust to the depression itself (at 30 inches) to supply the datum of the humidity; and here of course, under condensation, the moisture *increases* directly with the pressure. On the diagram this is very conspicuous in figs. 13, 14; and as the air approaches dryness, the line formed will be seen amalgamating with the curvature of the former experiments.

Tab. IX.—*Depressions under increased pressure.*

Barom. pressure. inches.	First Experiment.			Second Experiment.			Third Experiment.			Fourth experiment.		
	Temp. air.	Depression.	Humidity.	Temp. air.	Depression.	Humidity.	Temp. air.	Depression.	Humidity.	Temp. air.	Depression.	Humidity.
	°	°		°	°		°	°				
30	93.5	23.5	.24	93.5	23.7	.24	85.0	24.0	.15	86.4	26.8	.10
33		—		93.6	20.9	.26		—			—	
36		21.5	.29	93.8	17.8	.29		14.0	.18		22.8	.12
42		19.5	.34	94.3	15.5	.34	85.2	11.4	.21		20.7	.14

In the last experiment the air was maintained for a long time at each pressure, whence its results are perhaps entitled to greater confidence than the rest. The direct theoretical depressions, $d \times \frac{30}{p}$ would be 26°.8, 22°.3, and 19°.1, which corrected by the co-efficient before found, would become 26°.8, 25°.6, and 24°.7; these again would have to be diminished for the altered humidity to 26.8, 24·5, and 22.8; still, however, differing materially from the experiment, which I attribute to the difficulty of keeping up a sufficient draft at the high pressures, in consequence of which the humidity is not fairly estimated.

If we examine the first experiment we shall have,

The direct geometrical depressions,..............	23.5	19.6	16.8
These modified by co-efficient, .27..............	23.5	22.4	21.7
Corrected to the incipient state of humidity will be,	23.5	20.0	18.1
The observed depressions being in this case,......	23.5	21.5	19.5

nearly midway between the modified and the corrected numbers, and as much above the latter as they were below them in experiment 4,—so it will be not unreasonable to conclude that our formula would hold good for augmented depressions, if proper care were taken in conducting them.

We have now examined every case of depression that can be experienced in common air, and we may finally sum up this lengthy investigation by uniting the members of the formula, that it may comprehend both changes of humidity and changes of atmospheric pressure thus:—

$$d = 84 f' - f'' + .27 \left(\frac{d\,30}{p} - d \right).$$

The latter member of the equation may be converted into a table of multipliers for heights of the barometer other than 30, which will leave the table I have appended to the present paper applicable to all circumstances that can occur. The rule for its use will be given in the proper place.

§ 5.—*Depression of wet-bulb in other gaseous media.*

It has been seen that the theory of the wet-bulb thermometer is entirely based on the relation of the specific heats, or capacities, of water, of vapour, and of air. It may be made therefore to furnish an unexceptionable and easy method of solving the much-contested question of the relative capacity of different gaseous fluids, by substituting any of the latter for common air in the experimental determination of the depression.

By GAY LUSSAC's formula we perceive that the depression varies precisely in the inverse ratio of the air's capacity, c (see p. 405.) APJOHN's formula is based on the same datum ; thus the specific heat of vapour at 50° being 1129 (= 967 + 212 — 50) ; that of water being 1 ; and that of air $c = 0.267$; " one part of air in cooling through d degrees will raise the temperature of 0.267 part water through the same number, and will consequently be adequate to vaporize a quantity of water represented by $\frac{.267\ d.}{1129}$". Now, as $\cdot 267\ d\ (= c\ d)$ is a constant quantity, any change in the value of c must affect d in an opposite or inverse sense, that is $c' = \frac{c\,d}{d'}$, d' being the depression observed in other medium than common air.

As most likely to exhibit any difference of specific heat, and without reference to any prior determination of the question, I selected two gases, *hydrogen* and *carbonic acid*, as far at variance in essential points as could be wished, and proceeded with them exactly as had been done with ordinary air. On account of the mode of preparing the two gases by distillation through a water-trough, they entered the gasometer surcharged with moisture: and, as noticed below, even after being well dried by the acid in the chamber, they took up moisture from the discharge-pipe on their passage to the wet-bulb. I could only approximatively remedy this evil by immediately filling in common air, and finding how much moisture the latter also absorbed in its passage. The error was of course less, if at all, perceptible at the high temperatures, and in a fresh series of experiments it was obviated by the introduction of my tell-tale hair hygrometer.

Wishing to save the gas, it was made to pass into another gasometer instead of into the open air ; on which account the current both of hydrogen and of carbonic acid passed more slowly through the steam-heated tube than the air had done, and their temperature only rose to 160 and 170, in lieu of 180 and even 190 as at first. Here follow the readings which were considered as coincident, but, as before, there was difficulty in keeping the dry thermometer stationary,

TAB. X.—*Depressions with Hydrogen gas. First Series.*

	Therm. in air. °	Wet-bulb. °	Depression. °	Hygrometer.	Tension centesimal.	Tabular depression in dry air.	Ratio. d÷D
1. Through steam pipe,	92.0	67.8	24.2	—	?	37.1	
2. Ditto, steam on, ..	160.0	83.2	76.8	—	nearly dry.	81.5	.94
3. Ditto, ditto, ...	137.0	76.4	60.6	—	ditto.	65.3	.93
4. Ditto, cold, ...	93.8	67.5	26.3	44 ?	.17 ?	38.1	

The hydrogen of the gasometer in the first two experiments was supposed to be dry, but it was found that it acquired moisture in passing through the pipes, which had been moistened by the distillation of the hydrogen; the amount of error was estimated by filling common air in, and finding how much its depression differed from the full rate. The gas of 3, and 4 was passed out into a vessel containing the hair hygrometer; but still no great confidence was placed in the series, and on two subsequent days fresh gas was prepared.

Second Series.

5. Protracted current of hydrogen gas,..	85.4	60.0	25.4	
6. Common air treated exactly in the same manner, ...	90.6	59.0	31.6	= 29.1 at 85·4
Ratio of	29°.1	to	25°.4	as 1.00 to .87

This was still unsatisfactory, as there was no mode of testing the hygrometric state of the gas: I now therefore fitted the glass chamber enclosing the hair hygrometer, (as in fig. 1) and took the following readings after intervals of a day each.

	t	t'	d	h	Calc. Maxim. in Hydrogen.	Depress. in Atm. air.	Ratio. d÷D
7. Hydrogen, current,	87.8	60.5	27.3	8	29.5	34.8	.84
8. Ditto, full draft, ..	88.0	59.7	28.3	5	29.8	34.9	.86
9. Ditto, ditto, ...	84.0	57.1	26.9	4	28.0	32.8	.85
10. Ditto, ditto, ...	88.5	58.5	30.0	4	31.2	35.2	.88
11. Common air.	87.0	54.8	32.2	4 ?	33.5	34.4	
12. Ditto, ...	83.1	52.1	32.0	2	32.6	32.4	

Still a fourth series was thought necessary; and in this all access of moisture to the tubes being prevented by passing the gas over sulphuric acid before it entered the gasometer, and leaving it for a week to dry thoroughly, the hair hygrometer marked extreme siccity: precaution was also taken to cool the wet-bulb with ice below the depression point, before inserting it in the tube.

Fourth Series, Hydrogen gas.

	t	t'	d	h.	D	d÷D
13. Full draft,....	86.7	58.5	28.2	0	34.2	.82
14. Ditto, ...	85.0	57.4	27.6	0	33.4	.83
15. Ditto, ...	82.8	56.5	26.3	0	32.2	.81

This fourth series, on which every care was bestowed to ensure accuracy, confirming as it does the ratio of the prior experiments, certainly tends to prove that hydrogen produces a less depression than common air in the proportion of 82 to 100 ; and consequently that the specific heat of this gas for equal volumes should be 1.22, that of atmospheric air being 1.

Tab. XI.—*Depressions with Carbonic Acid.*

	Temp. air. t °	Wet-bulb. t' °	Depression. d °	Hair hygr.	Tabular depression for dry air. D	Ratio. $\frac{d}{D}$
1. Current through steam pipe, ..	91.7	66.2	25.5	(acquired moisture .20 ?)	36.3	?
2. Do. steam on,	161.0	85.0	76.0	Nearly dry ?	82.2	.94
3. Do.quicker draft,	160.0	81.5	78.5	ditto,	81.5	
4. Common air, ..	86.8	60.8	26.0		34.3	

The experiment with common air shews that the passages still imparted moisture to the amount of full ·12, and therefore vitiated the result as with hydrogen. The trial was renewed with the precaution of employing the hair hygrometer.

				h		d	D	$d \div D$
5. Short glass tube,	83.6	55.0	28.6	5	Corrected	30.1	32.6	.92
6. Ditto, ...	86.2	55.2	31.0	3	for dry	32.0	34.0	.94
7. Ditto, ...	83.7	53.6	30.0	3	air or	31.0	32.6	.95
8. Common air,....	88.2	54.5	33.7	3	max. dep.	34.8	35.0	

Here again the depression in carbonic acid gas is proved to be 94 hundredths of that in common air, whence the specific heat of this gas should turn out 1.06, air being 1.00. A third series was taken :

8. Well dried, ..	88.7	56.2	32.5	0		32.5	35.3	91
9. Ditto, ...	84.8	55.1	29.7	0.5		29.9	33.2	90
10. Ditto, ...	89.6	57.2	32.4	1		32.8	35.8	90

In the last three experiments which were made with the precautions I have described, in the hydrogen experiments, (13-15) a little of the latter gas was mixed ($\frac{1}{20}$th) with the carbonic acid ; while in experiments 6, 7, common air may have been present to the same extent. We may therefore assume the maximum depression in dry carbonic acid to be about 92 per cent. of that in atmospheric air; and its spec. heat = 1·087.

Although these unexpected results are supported by their great uniformity, I still feel hesitation in inviting for them the implicit confidence of chemists, in opposition to the very opposite conclusions of other experimenters. Had the specific heat of one gas proved in *defect* and the other in *excess*, it would have been more consonant with the analogy of their specific gravity,—but that two gases so strongly contrasted, should both err, on the same side, I own to be plausible evidence against me. Still I hardly think that the 8 per cent. discrepancy in the carbonic acid experiments is within the limits of experimental error ; and the 18 per cent. of the hydrogen is certainly more than I am willing to allow to be attributable to such a cause.

At any rate it must be conceded that the method itself possesses superior facility to the process of De la Roche and Berard*, also followed by Haycraft†, or to that more recently followed by my friends Messrs. F. Marcet and De la Rive of Geneva‡.

It may be as well to recite the conflicting values arrived at by these and other authors, including M. Dulong§, whose mode of investigation by the velocity of sonorous vibrations in the respective gases, was most ingenious in itself, and perhaps better entitled to respect than any other.

Tab. XII.—*Specific heat of gaseous bodies by volume, under constant pressure.*

	By De la Roche and Berard.	By Haycraft	By Marcet and De la Rive.	By DuLong	By wet-bulb depression.
Atmospheric air,	1,000	1,000	1,000	1,000	1,000
Oxygen.	976	1,000	1,000	1,000	—
Hydrogen, ...	903	1,000	1,000	1,000	1,220
Nitrogen,.......	1,000	1,000	1,000	1,000	—
Carbonic Acid, .	1,258	1,000	1,000	1,175	1,087
Carburett. Hyd.	1,553	1,060	1,000	1,531	—
Carbonic oxide,	1,034	—	1,000	1,000	—
Nitrous gas, ..	1,350	—	1,000	1,160	—

Notwithstanding the tendency of my own experiments, every one must feel a prejudice on a view of this table in favor of the conclusions of the English and the Genevese philosophers; namely, that all the gases have the same specific heat.

In such case however it will be necessary to assign some other cause for the indubitable results above given, or our judgment must be suspended, until a careful repetition of similar experiments may determine the conditions with other gases, and lead to some definite conclusions for the whole of this most interesting question.

§ 5.—*A few illustrations of the wet-bulb theory.*

My paper has expanded to such a formidable length, that I am loath to burthen it with many "last words:" yet I cannot refrain from pointing out an instance or two of practical application, and shewing that d and f' are as important elements in the play of meteorological phenomena as the dew-point itself, and require equally to be studied by naturalists.

1. The Baron Hugel remarked, that ice was formed in Cashmír with the thermometer at 44°‖ at an elevation of 15,000 feet: whence he concluded that the freezing point rose as the boiling point fell. This startling paradox is now readily explained: the air of the plains is dry enough at all times in those latitudes:—it becomes relatively drier in expanding on the mountains, while the depression simultaneously

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[*] Annales de Chimie, lxxxv. 126.

[†] Annales de Chimie, xxvi. 298.

[‡] Ditto 1829, xxxv. 5.

[§] Ditto, xli. 113.

[‖] See J. A. S. vol. v. p. 186.

increases. When $t = 44°$, $D = 15.5$ which $+ .27\left(\frac{d\ 30}{16.8} - d\right)$ for 15,000 feet, $= 18.5$, so that if the air were already charged with a third of its saturating quantity of vapour, the depression of 13 degrees would still cool a surface of water below the freezing point.

Gay Lussac points out a similar fact noted on Saussure's ascent of Mont Blanc. "En faisant tourner sur le *Col du géant* un thermométre dont la boule était enveloppée d' une éponge, il a obtenu un refroidissement de 9°.3 C (16°.7 Farh.) au dessous de la température de l'air qui était de 10°.1 (50°. 2 F.) ainsi l' evaporation peut concourir avec le rayonnement pour déterminer la congélation de l'eau à la surface de la terre, dans un air dont la température serait de plusieurs degrés au-dessus de zéro*."

2. The formation of hail is readily explained on the same principle. The drops of water passing through a stratum of very attenuated dry air, perhaps even warmer than the saturated cloud they have quitted, are cooled to congelation—nay, most likely much below it, since they are not remelted in their onward progress to the earth, but are apparently enlarged by deposition of fresh moisture. Hail is seldom observed to fall in damp weather.

Thus also, frozen clouds (cirri) may be found at elevations in the air much lower than would belong by theory to a temperature of 32°, and their dissipation while still in a frozen state, is also accounted for.

3. The increase of rain drops as they approach the earth has been satisfactorily proved to originate in the deposit of atmospheric moisture on their surface, cooled below the dew-point temperature.

4. Why is not the air at sea always surcharged with moisture? The actual tension of vapour in the air does not depend on t but t': now the bulk of the ocean maintains an uniform temperature, in general a few degrees below that of the air in the day time: f' therefore being then always less than f, saturation cannot take place, however much water may be present. But there is another reason; salt-water has a lower tension than pure water; that is, were it heated to t, its tension would not be f. It boils at $213\frac{1}{20}$ (?) in lieu of 212°, which reduces its tension about one part in 40—and the same proportion will hold good, on Dalton's hypothesis, for lower temperatures. In clear nights the air on ship board must always be fully charged with moisture, and hence the heavy dew on deck.

5. An analogous explanation can be given of the curious fact observed by M. Clement in 1821†, that if a thermometer bulb coated with lint be dipped in a saturated solution of any salt (or the salt in powder) and be held in aqueous vapour of 212°, it will acquire itself

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* Annales de Chimie, xxi. 92.

† Ure's Chemical Dictionary, p. 284.